The *Journal of Cotton Science 9:121–127 (2005)*
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ENGINEERING AND GINNING

Comparison of Cotton-based Hydro-mulches and Conventional Wood and Paper Hydro-mulches – Study 1

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ABSTRACT

Soil erosion from steep slopes, bare soil, or construction sites is a problem that can create on-site gullies, make revegetation difficult, and adversely affect downstream water bodies and aquatic ecosystems. Mulches have been widely used to mitigate the effects of erosion. One common type of mulch, hydro-mulch, uses shredded wood or paper that is mixed with water and applied with an applicator gun. In this study, conventional wood and paper hydro-mulches were compared with cottonseed hulls and three types of processed cotton gin by-products. The mulches were applied at two rates, 1121 and 2242 kg/ha (1000 and 2000 lb/acre). Comparisons were made on the time to runoff, sediment loss, mulch loss, and mulch coverage (C-Factor). The cotton-based mulches (cottonseed hulls and cotton gin by-products) performed equal to or better than conventional wood and paper mulches in reducing soil loss during a simulated 6.35-cm/h (2.5-in/h) rainfall intensity event. Likewise, a lower percentage of the cotton-based mulches were washed-off during the rain event than with the conventional wood and paper hydro-mulches. The coverage factor and the time to runoff associated with the wood and paper mulches were higher than for any of the cotton-based mulches. Overall, the cotton-based mulches showed promise in erosion control applications.

Excessive soil erosion creates on-site problems, such as gully formation, which requires costly repairs, and off-site problems, such as reservoir filling and aquatic habitat degradation, associated with downstream transport of sediment (Flanagan et al., 2002b). Excessive erosion occurs most often on sites with steep slopes and/or bare soil conditions, but erosion can also be accelerated by cultivation, construction, or logging activity. The potential for excessive erosion is greatest in the period between soil disturbance and re-establishment of vegetation or other permanent cover. To provide temporary protection and minimize soil erosion during this period, mulches are often applied to recently disturbed sites. Straw, shredded paper, wood chips, and gravel have all been widely used for mulching (Agassi and Ben-Hur, 1992; Buchanan et al., 2002). A combination of grass seed and mulch is often applied to provide temporary cover and accelerate revegetation (Flanagan et al., 2002a).

The effectiveness of mulches has been known for some time. Mulches applied on the surface of disturbed sites reduce erosion by absorbing moisture and intercepting rainfall energy, which reduces soil surface sealing, particle detachment, and runoff potential (Mannering and Meyer, 1963; Lattanzi et al., 1974). Mulches also reduce overland flow velocities once runoff occurs (Kramer and Meyer, 1969; Meyer et al., 1970; Meyer et al., 1972). The practical application of this knowledge has influenced the agricultural industry through the wide-spread adoption of residue management in cultivated agriculture and the construction and mining industry with erosion control regulations on work sites.

Typical organic mulches are plant residues or plant by-products that are viewed as waste products. Wheat straw, waste paper, pine needles, and wood chips from yard wastes and forest site clearings have all been widely used because of their availability and affordability. In areas of the country with excessive amounts of other organic wastes, these wastes could be used in mulch applications.

In this study, mulches produced from by-products of the cotton industry were evaluated. Mulches were formed with cottonseed hulls and with a patented cotton by-product (COBY) process (Holt

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and Laird, 2002). It was predicted that the COBY mulches would provide adequate soil cover and would perform well in erosion reduction because of their fibrous nature. The objective of this study was to evaluate the performance of cottonseed hulls and COBY as mulches for use in erosion control applications.

MATERIALS AND METHODS

Experimental setup and treatment application. An erosion study was performed at the USDA-ARS, Cotton Production and Processing Research Unit in Lubbock, Texas. The soil used for this study was a sandy clay loam consisting of 20% clay, 17% silt and 63% sand. Prior to testing, the soil needed for each run was processed over a shaker table (sieved), loaded into nylon tote bags, and stored in a dry location for later use. The sieving was intended to break up clods and make the soil more uniform. The size of the shaker table screen was 6.35 mm^2 (0.25 in^2). The day before conducting the runs, 9 to 12 trays were each loaded with approximately 195 kg (430 lb) of soil. Each tray was 0.61-m (2-ft) wide by 3.05-m (10-ft) long and 7.6-cm (3-in) deep for a volume of 0.143 m^3 (5 ft^3). The soil was packed and leveled to obtain a soil density of 1.4 Mg/m^3 (87.4 lb/ ft^3), which was similar to the average bulk density of the top 15 cm (5.9 in) of soil with a similar texture from dryland and irrigated cotton fields in four counties near Lubbock (Bronson et al., 2004). After packing and leveling the soil, mulch was hand applied to the soil at 1121 kg/ha (1000 lb/acre) or 2242 kg/ha (2000 lb/acre). The six mulches evaluated in this study were wood hydro-mulch, paper hydro-mulch, cottonseed hulls, COBY produced from stripper waste (COBY Red), COBY produced from picker waste (COBY Yellow), and COBY produced from ground stripper waste (COBY Green). None of the mulches used in this study had any surfactants or polyacrylamides added during application. For the initial evaluation it was deemed best to apply the product by hand to ensure the specified mulch rates were obtained, because there was no consistent means of precisely measuring the amount of product applied to a given area using a hydro-mulcher.

After the mulches were evenly distributed across the surface of the soil area, water was sprayed onto the mulch at a volume that was equivalent to the amount applied if the mulch had been applied with a hydro-mulcher/seeder. The water added to each tray was 3.78 L (1 gal) for the 1121 kg/ha (1000 lb/acre) treatments and 7.57 L (2 gal) for the 2242 kg/ha (2000 lb/acre) treatments. After the water was applied, the trays were stored in a covered area for a minimum of 16 h before subjecting them to simulated rain. Before testing, digital images were taken from a predetermined 0.37-m^2 (4-ft^2) section in the front- and back-half of each tray to determine the amount of coverage obtained by each mulch application. Three trays were then loaded onto a cart, tilted to a 9 degree slope, and positioned under the spray nozzle of the rain simulator (Fig. 1). The slope of each tray was verified using an Empire Magnetic Protractor (Northern Tool and Equipment; Burnsville, MN). The highest point of each tray was approximately 3.96 m (13 ft) below the spray nozzle. The spray nozzle used was a 1/2-HH-Brass-50W, wide angle/square spray nozzle (Spraying Systems Company; Wheaton, IL). A barrel was placed on a scale under the flume of each tray to catch the soil and water runoff. The water supply to the nozzle was connected to the main water supply and passed through a flow meter and pressure gauge to assist in maintaining constant pressure and flow rate to the nozzle. The simulated rain event produced a rainfall intensity of 6.35 cm/h (2.5 inch/h).

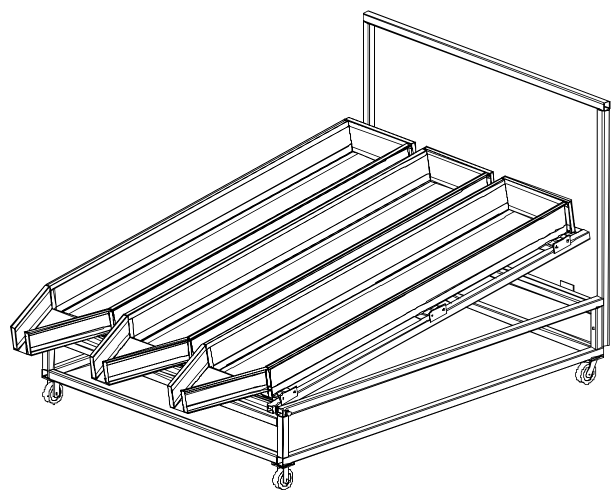

Figure 1. Drawing of soil erosion trays on the tray cart.

During the rain simulation, the data collection procedure was used as follows: 1) record time rain started, 2) activate scale data loggers to record (every 5 s) the amount of runoff collected in the barrels under each tray's flume, 3) record the amount of time until runoff occurred for each tray, 4) once runoff occurred, grab samples were collected in pre-weighed glass jars every 5 min for 25 min, 5) after 30 min of runoff time had elapsed for a given tray, scale data logging was ceased and the collection barrel removed, 6) the rain continued until all three trays had experienced 30 min of runoff. This procedure was repeated for each series of three trays until all 36 experimental runs had been completed.

The grab sample jars collected for each tray were oven dried at a temperature of 82.2 °C (180 °F) for 48 h, and the remaining dry soil weighed. The soil in each jar was then removed and stored in plastic bags for analytical analysis of the amount of organic matter collected (i.e. mulch). The grab samples were used as a backup quality assurance measure in the event the scale dataloggers failed. The calculated sediment loss was based on the total quantity of soil collected in the barrels under the flume of each tray over the 30 min of runoff and was corrected for the amount of mulch captured.

Image analysis. The digital images were used to determine coverage factor. The images were analyzed by first obtaining a 3D scatter graph of the images where the x,y,z positions were assigned based on the whether the area was ground or mulch. In some cases, the 3D scatter-plot revealed a clearly separable set of dividing plains that could be used as a set of linear discriminant functions. For these images, the dividing plains were determined directly from the 3D scatter plots. In other cases, the classes were not clearly separable, and Bayesian pattern recognition techniques were used to determine the set of linear discriminant functions.

In order to use a Bayesian classifier, the covariance, mean, and population size statistics were identified. From these basic statistics, conditional probabilities were derived which form the basis for the Baye's Classifier. To obtain the statistics for each of the images in the study, two individuals took each image and classified a subset of the pixels from each of the three classes. From these training sets, the mean color and covariance of the colors for each class was determined. To estimate the size of the population from each class, the same two individuals visually estimated the coverage to the nearest 5%.

Mulch products. The cottonseed hulls, wood hydro-mulch, and paper hydro-mulch were purchased from commercial vendors and evaluated "as is". The raw material used for the COBY Yellow and COBY Green product was acquired from two commercial gins. The COBY Red raw material, which included motes, was obtained from the USDA-ARS Cotton Ginning Laboratory in Lubbock, TX. The picker waste (COBY Yellow) was obtained from a gin in Arizona. The stripper waste (COBY Green) that had been ground through a tub grinder was obtained from a gin located within 4.8 km (3 mi) of the ginning laboratory. All the gin by-products were processed using the COBY Process at the USDA-ARS, Cotton Production and Processing Research Unit in Lubbock, TX. Table 1 shows the averaged results from three repeated measures of a sieve analysis for the mulches used in this study.

Figure 2 shows a schematic of the process used to produce the COBY material. The raw material was loaded using a pneumatic conveyer into a live-bottom bulk feed bin with five 22.9-cm (9-in) augers. Upon

Table 1. Average percentage of mulch remaining on each sieve from three replicated analyses for each of the mulches

Sieve size [mm (in)]	Percentage of mulch remaining on the sieve					
	COBY green	COBY Red	COBY yellow	Hulls	Paper	Wood
22.2 (7/8)	0.0	8.6	2.6	0.0	0.0	2.2
19.0 (3/4)	0.1	2.9	7.4	0.0	0.8	0.7
15.8 (5/8)	1.4	8.6	6.8	0.0	0.0	0.9
9.5 (3/8)	41.9	34.0	44.5	0.0	0.5	16.2
7.9 (5/16)	3.4	2.7	5.1	0.0	0.4	1.5
3.2 (1/8)	45.4	37.4	29.4	90.3	15.7	35.7
0.78 (1/32)	3.7	2.6	2.0	4.6	23.0	10.5
0.18 (1/140)	3.0	2.3	1.5	2.8	41.6	21.3
0.079 (1/318)	0.9	0.7	0.4	1.7	13.2	7.9
0	0.3	0.3	0.3	0.6	4.8	3.2

exiting the feed bin, the gin by-products were sprayed with a gelatinized starch solution containing either a red, green, or yellow dye for coloring depending on the raw material being processed. The starch in the COBY process was added in an effort to reduce abrasion on the processing equipment resulting from the raw material. The sprayed material was conveyed in twin 30.5-cm (12-in) cut-and-fold mixing augers to a side-feeder that force-fed the by-product slurry mix into an Insta-Pro model 2000 extruder (Insta-Pro International; Des Moines, IA). The product exiting the extruder was conveyed to a belt dryer, where the product was exposed to 135 °C (275 °F) air. Upon exiting the dryer, the material was loaded into nylon tote bags for storage.

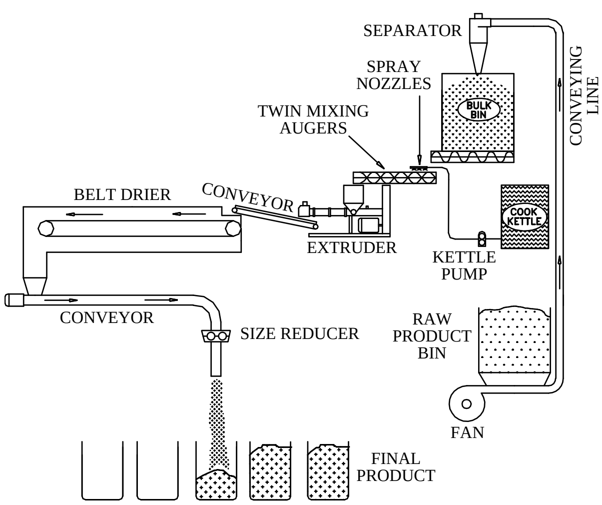

Figure 2. Schematic of the process used to produce the COBY mulch.

The gelatinized starch slurry consisted of 0.453 kg (1 lb) of starch to every 3.78 L (1 gal) of water in the cook tank. The starch slurry was applied at a consistent rate via a piston pump driven by a 0.56-kW (0.75-Hp) DC motor regulated by a closed-loop control system. The control system was comprised of flow meter with a 0 to 10 VDC output signal to the DC drive regulating the speed of the motor driving the starch pump. The amount of starch added to the by-products was 5% by weight of the products (i.e. 6.79 kg/min [15 lb/min] of by-products had 0.34 kg/min [0.75 lb/min] of starch added).

Feed rate from the bulk feed bin was determined from a mathematical relationship established prior to producing the mulch. A DC drive connected to a 0.75-kW (1-Hp) DC motor regulated the output from the bulk feed bin. The DC motor powered the feed bin augers through a 64 to 1 gear and sprocket reducer. Prior to processing the mulch, the raw material was loaded into the bulk feed bin and emptied at four different drive settings into a collection bin placed on a scale. The amount of material emptied during 15 min of operation was recorded for each of the four settings. This procedure was repeated three times for each setting in order to develop the mathematical formula necessary to determine the raw material output of the bulk feed bin at various intermediate settings on the DC drive. Temperatures of the extruder were recorded from two type-K thermocouples placed within the thermocouple wells located on the extruder barrel.

Experimental design and data collection. The six mulches evaluated in this study were COBY Red, COBY Green, COBY Yellow, paper hydro-mulch, wood hydro-mulch, and cottonseed hulls. Each of the six mulches was applied at two application rates, 1121 and 2242 kg/ha (1000 and 2000 lb/acre). Each treatment (mulch plus application rate) was replicated three times. The experiment was arranged as a randomized complete block design with treatments blocked by tray position (south, center, and north) on the cart (i.e. each treatment had one run in all three of the tray positions).

Standard analysis of variance techniques were used to analyze the various data associated with the mulches to determine statistically significant differences among the twelve treatments by the Ryan-Einot-Gaberiel-Welsch multiple range test at the 95% confidence interval (release 8.02; SAS Institute Inc.; Cary, NC). The response variables evaluated from the data included time to runoff, soil loss by grab samples, sediment loss based on total catch, percentage of mulch washed-off, and mulch coverage factor (C-Factor).

RESULTS AND DISCUSSION

Several factors are important in determining the benefits of erosion control mulches. The results for time to runoff, soil loss by grab samples, and sediment loss based on total catch are shown in Table 2. The time to runoff was significantly different among mulch types ($P = 0.001$) but not among mulch rates ($P = 0.195$) or the interaction between mulch type and rate ($P = 0.605$). The paper mulch with an average time to runoff of 20.3 min took significantly longer time to runoff than any of the cotton-based mulches. The wood mulch was second with an average time of 17.6 min, and it took significantly longer than the cot-

Table 2. Response variables of time to runoff, sediment loss in grab samples, and sediment loss from total catch for each of the mulch treatments evaluated

Mulch	Time to runoff (min)[w]	Sediment loss in grab samples (g)[x]	Sediment loss from total catch (kg/ha)[y]
COBY green	13.9 bc[z]	13.4 bc	18,600 bc
COBY red	12.6 bc	10.9 bc	16,000 bc
COBY yellow	11.0 c	12.6 bc	21,200 b
Hulls	9.9 c	4.5 c	6,100 c
Paper	20.3 a	27.6 a	35,400 a
Wood	17.6 ab	21.9 ab	28,900 ab
Source		*P*-values	
Mulch	0.001	0.001	<0.001
Rate	0.195	0.797	0.181
Mulch*rate	0.605	0.934	0.731

[w] The average amount of time that elapsed before water ran off the trays in a steady stream.

[x] The average total amount of soil collected in the five grab sample jars used during a run.

[y] The calculated amount of sediment loss occurring in the erosion tray after experiencing 30 min of runoff from a 6.35-cm/h (2.5-in/h) rain event.

[z] Means within a column followed by the same letters are not significantly different at the 95% confidence limit according to the Ryan-Einot-Gaberiel-Welsch multiple range test.

tonseed hulls before runoff began. Of the cotton-based mulches, COBY Green took the longest time to runoff with an average time of 13.9 min, while cottonseed hulls took the shortest time with an average time of 9.9 min. The potential reduction in erosion associated with this difference is not substantial as illustrated by the soil loss results, which will be discussed in detail. The differences in time to runoff correspond with the coverage factor shown in Figure 3. The greater the coverage, the longer the time before runoff began. The increase in coverage improved the initial water retention capacity of the mulches. Water retention could be due to absorption of the water by the mulches, such as the paper mulch, or due to the formation of terraces/levees that hold the water in place in the mulch, such as the wood mulch.

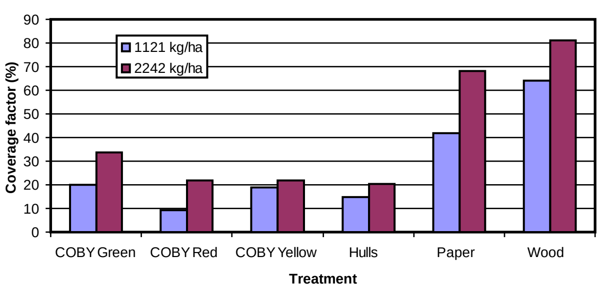

Figure 3. Average percentage of soil coverage (coverage factor) resulting from the six mulches at the two application rates evaluated prior to the rain event.

While other factors influence the performance of mulches, soil loss is the primary indicator of performance. The results from two of the soil loss parameters evaluated, sediment loss estimated by the grab samples and total soil catch, are shown in Table 2. The sediment loss by grab samples, the cumulative amount of soil collected in the sample jars, was significantly different among mulch types ($P = 0.001$), but not among mulch rates ($P = 0.797$) or the interaction of mulch type and rate ($P = 0.934$). The paper mulch had significantly more soil collected (27.6 g [0.97 oz]) in the sample jars than any of the cotton-based mulches. The quantity of soil collected from the wood mulch was second highest (21.9 g [0.77 oz]), which was not significantly higher than any of the COBY mulches, but was significantly greater than the cottonseed hulls (4.5 g [0.16 oz]).

The sediment loss (kg/ha) values were calculated from the amount of soil collected in the collection barrels underneath the flume of each tray and the area of the tray. The sediment lost may appear extreme; however, when considering the plots are indicative of an unconsolidated sandy clay loam soil on a 9 degree slope subjected to a 6.35-cm/h (2.5-in/h) intensity rainfall, the results are not unexpected (Flanagan et al. 2002a). Sediment loss was significantly different among mulch types ($P < 0.0001$), but not among rates ($P = 0.181$) or their interaction ($P = 0.731$). Similar to the grab sample soil loss results, the paper mulch resulted in significantly higher soil erosion (35,400 kg/ha [15.79 ton/acre]) than any of the cotton-based mulches. Wood had the second highest average sediment loss (28,900 kg/ha [11.56 ton/acre]), but was not significantly different from either paper or the COBY based mulches. The lowest average sediment loss occurred on the plots containing cottonseed hulls (6,100 kg/ha [2.44 ton/acre]), which had significantly lower sediment losses than either the paper or wood hydro-mulches. Among the COBY mulches, COBY Red had the lowest average soil loss at 16,000 kg/ha (6.40 ton/acre) and COBY Yellow had the highest at 21,200 kg/ha (8.48 ton/acre). The sediment loss results based on grab samples and on total soil catch should be similar, because the grab samples were used as a backup quality assurance measure in the event of problems with the scale dataloggers recording the weight of the barrel under each flume.

Generally, coverage was higher with the higher application rate, but increasing the application rate for COBY Yellow and cottonseed hulls did not result in as big a change in C-Factor, which was noted in the other mulches (Fig. 3). The coverage factor was significantly different among mulch types ($P < 0.0001$), rates ($P < 0.0001$), and their interaction ($P = 0.023$). Contrary to the belief that more coverage would equate to less soil loss, the opposite trend was observed based on the data presented in Fig. 3 and Table 2. A possible explanation for this is provided by Fig. 4, which shows paper and wood hydro-mulches had a greater percentage of the mulch washed-off during the rain event than did any of the cotton-based mulches. From visual observations during testing, the cotton-based mulches tended to cling to the soil better than either the wood or paper mulches. The wood mulch did form mini terraces/levees which helped slow erosion; but once those terraces/levees broke, the removal of soil and mulch increased. The paper mulches tended to absorb water, but once the mulch and soil was saturated, the mulch floated off the soil much more readily than any of the other mulches evaluated. The percentage of mulch that washed-off was significantly different among mulch types ($P < 0.0001$), rates ($P < 0.0001$), and their interaction ($P = 0.007$). The data indicates that the increased soil erosion occurred on plots where the percentage of mulch loss was higher. Even though the amount of coverage for the cotton-based mulches was poor, they appeared to adhere to the soil better, so soil loss was reduced compared to those mulches that were removed by the rain event.

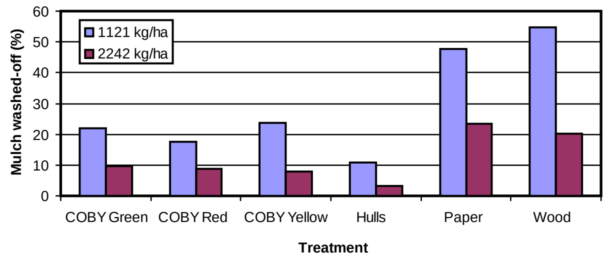

Figure 4. Average percentage of mulch washed-off after the rain event for the two application rates used for the six mulch treatments evaluated.

One characteristic of the wood and paper mulches that may have caused them to exhibit higher coverage factors than the cotton-based mulches, other than contrasting well with the color of the light red sandy clay loam soil, was the sizing of the mulch. More than 75% of the wood and paper mulches were smaller than 3.2 mm (1/8 in) compared to the COBY products which had no more than 54% (COBY Green) of particles in the same range (Table 1). The only cotton-based mulch with a large percentage of particles less than 3.2 mm (1/8-in) was the cottonseed hulls, which had 100%. Overall, a combination of sizing above and below 3.2 mm (1/8 in) may be an important element in the COBY mulches obtaining coverage similar to the wood and paper mulches. Desirable coverage may be obtained by having just enough longer material to visually appeal to the eye with enough short material to fill the voids left by the larger material.

The results indicate that the cotton-based mulches can reduce soil erosion compared with conventional wood and paper hydro-mulches, but the C-Factor needs to be improved since the industry is visually driven by proper application rates. Initial customer satisfaction that the applicator did indeed apply the quantity of material purchased is essential.

CONCLUSIONS

Overall, the cotton-based mulches performed well in reducing soil runoff compared with conventional wood and paper hydro-mulches. Even though the mulches evaluated in this study were hand applied, they were manufactured for applications using a hydro-mulcher. The rationale for not using a hydro-mulcher in this initial study was to be able to precisely regulate the amount of product distributed over the soil area. One area associated with the cotton-based mulches in need of refinement is the amount of coverage (C-Factor). The C-Factor could be improved by reducing the size of the material further, but it is uncertain at this time whether or not that would be necessary, since material applied with a hydro-mulcher may distribute the product more uniformly than hand application. In spite of the low coverage, the cotton-based mulches performed equal to or better than the conventional wood or paper hydro-mulches in reducing soil erosion from a 6.35-cm/h (2.5-in/h) simulated rain and show promise for use in erosion control applications. Cottonseed hulls performed as well as the COBY mulches in reducing soil loss and better than wood and paper hydro-mulches, but cottonseed hulls currently have a market and could become cost prohibitive compared with processed gin by-products depending on their market value. Based on the results of this study, additional erosion studies are planned to evaluate the same mulches applied as typical hydro-mulches using an application gun. Also, increased mulch rates will be used in an attempt to further reduce erosion. In regards to coverage factor, studies will be undertaken to address the deficiencies of the cotton-based mulches noted in this study.

ACKNOWLEDGEMENTS

The partial support of this research by Cotton Incorporated and Summit Seed, Inc. is gratefully acknowledged.

DISCLAIMER

The use of product or trade names does not constitute an endorsement by the USDA-ARS over other comparable products. Products or trade names are listed for reference only.

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